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published in
Human Brain Mapping
2005

DOI (link to publisher)
10.1002/hbm.20071

document version
Publisher's PDF, also known as Version of record

◆ Human Brain Mapping 24:69–78(2005) ◆

Prioritizing New Over Old: An fMRI Study of the Preview Search Task

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Abstract: In visual search, observers can successfully ignore temporally separated distractors that are presented as a preview before onset of the search display. Previous behavioral studies have demonstrated the involvement of top–down selection mechanisms in preview search, biasing attention against the old set in favor of the more relevant new set. Using functional magnetic resonance imaging, we replicate and extend findings showing the involvement of superior and inferior parietal areas in the preview task when compared to both a relatively easy single-set search task and a more effortful full-set search task. In contrast, the effortful full-set search showed activation in the dorsolateral prefrontal cortex when compared to the single-set search, suggesting that this area is involved in rejecting additional distractors that could not be separated in time. *Hum Brain Mapp 24:69–78, 2005.* © 2004 Wiley-Liss, Inc.

Key words: selective attention; attentional capture; spatiotemporal segmentation; visual marking; visual search; superior parietal; precuneus; dorsolateral prefrontal; inferior frontal; middle frontal

INTRODUCTION

Our visual world changes as objects continuously appear and disappear. In this changing world, new objects may be of particular importance, providing novel information for the observer. Some authors have argued that new objects automatically capture attention in a bottom-up fashion, especially when they are accompanied by abrupt luminance increases [Theeuwes, 1994; Yantis and Jonides, 1984]. An important question for understanding human visual search is whether observers can also actively anticipate the appearance of new objects, and prioritize these objects to facilitate selection. Several lines of evidence indicate the existence of such active top–down mechanisms. For instance, Folk et al. [1992] suggest that new object onsets only capture attention if the observer is actually anticipating a target stimulus defined by an onset. If the observer expects the target to be defined by color, onsets do not interfere with selection.

Other evidence for top–down control over new object selection comes from the *preview* paradigm [Watson and Humphreys, 1997; see also Treisman et al., 1983]. In the preview paradigm, observers carry out a visual search for a target item amongst several distractor items. Unlike standard visual search tasks, one set of distractors (typically half the total number of items) are presented first, whereas the remaining set of distractors, including the target, are added later (usually after 1 s). Observers thus get a preview of completely irrelevant "old" distractors, which are best ignored in favor of the more relevant "new" set. The results indicate that observers can indeed prioritize the new set over the old. The search slope in the preview condition is

Contract grant sponsor: Medical Research Council (UK).

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Received for publication 4 August 2003; Accepted 9 June 2004
DOI: 10.1002/hbm.20071
Published online in Wiley InterScience (www.interscience.wiley.com).

around half what one would expect if observers had been searching the entire set including the old distractors (measured by a full-set baseline condition in which both sets of items are presented simultaneously), and it can equal the slope when the second set of items is presented alone, without the previewed distractors (the single-set baseline condition). Theeuwes et al. [1998] have shown that observers can prioritize at least 15 new items in preview search, a number exceeding the maximum capacity of four new items thought to capture attention in a bottom-up fashion [Yantis and Johnson, 1990; see also Pylyshyn and Storm, 1988]. To show that the preview benefit is under top–down control, we not only need to show that observers can prioritize the new items, but also that they do not have to. Evidence for this comes from studies using probe detection as a measure of the allocation of attention. In these studies, participants carry out a standard search task on most trials, but are cued in some trials to detect a small probe dot on one of the search items (with probes equally likely to appear on an old item as on a new item) [Humphreys et al., in press; Olivers and Humphreys, 2002; Watson and Humphreys, 2000]. When embedded in the search task, probes on new items are detected better and faster than are probes on old items. However, when probe detection becomes the main task the difference between old and new items decreases, or even disappears completely. This indicates that the new objects are not automatically prioritized, but only when relevant to the task.

In addition, if the prioritization of new objects were under top–down control, we would expect the preview benefit to be subject to limited-capacity attentional resources. In support of this, we have found that secondary tasks presented either during or preceding the preview display affect search through the second display [Humphreys et al., 2002; Olivers and Humphreys, 2002; Watson and Humphreys, 1997]. For instance, Olivers and Humphreys [2002] used a secondary task creating a temporary lapse of attention, termed an "attentional blink" [Raymond et al., 1992], followed by a preview display, and finally a search display. The more the preview display fell inside the attentional blink period of around 500 ms after the secondary task, the slower the subsequent search became, despite the attentional blink being over by the time the search display appeared.

The above studies show that observers can make use of the spatiotemporal dynamics of the display to bias selection against old visual objects in favor of new ones, and that some top–down processing is required to optimize such prioritization. One way in which this may be implemented is through visual marking [Watson and Humphreys, 1997]. Originally, visual marking was conceived as a process of actively inhibiting the locations of old items. For this, the attentional system would have to first set up and then suppress a spatial representation of the preview display. When the search set is then added, the new locations will receive priority in search. Recently, Donk and Theeuwes [2001] have argued against such an account. They reasoned that the new onsets capture attention automatically [Yantis and Jonides, 1984] and that there is thus no need for any top–down mechanisms in the preview task.

The present study sought to explore the brain areas involved in the preview task. If observers indeed actively make use of the spatiotemporal dynamics to segment new from old, we may expect top–down attention-related brain areas to be active. A prime candidate is the posterior parietal cortex. The posterior parietal cortex has now been implicated in numerous attention paradigms involving various spatial and nonspatial tasks. It is thought to be part of a general top–down frontoparietal network biasing selection against irrelevant stimuli in favor of relevant target information [for reviews see Corbetta, 1998; Kanwisher and Wojciulik, 2000; Kastner and Ungerleider, 2000]. It is likely then, that such a general network will be involved also in biasing attention against old information in search. There is also evidence of parietal involvement specifically in using dynamic spatiotemporal cues for selection. For instance, Gottlieb et al. [1998] found single cells in the lateral intraparietal area (LIP) of the monkey to be responsive when an object entered the receptive field through a new onset (i.e., when it was a new object) rather than through an eye movement (i.e., when it was an old object). In a functional magnetic resonance imaging (fMRI) study on humans, Coull and Nobre [1998], using a combined spatial/temporal cueing task, found parts of the intraparietal sulcus (IPS) and superior parietal lobule (SPL) to be active during spatial orienting, temporal orienting, or the combination of spatiotemporal orienting. Other neuroimaging studies have found the SPL to respond mainly to the cue rather than to the target, suggesting that it is involved in setting up or maintaining an expectation, in anticipation of the target [Corbetta, 1998; Kastner et al., 1999; Shulman et al., 1999]. The same conclusion can be reached based on patient studies indicating that the posterior parietal lobe is crucial in setting up, maintaining, or disengaging spatial attention [Friedrich et al., 1998; Posner et al., 1984, 1987].

Recently, Pollmann et al. [2003] used a preview task to investigate the brain areas underlying spatiotemporal selection. They found the SPL to be activated earlier and to a greater extent during a preview task, relative to both single-set and full-set search baselines. From this the authors concluded that the SPL might be involved in setting up a spatial representation of the previewed items. This spatial representation would then serve as a basis for an attentional bias against the old, favoring the appearance of the new items, as is proposed under the visual marking account. Although visual marking was originally conceived as a spatial process, recent behavioral evidence suggests that old objects may be deprioritized through properties other than (just) their locations [Braithwaite et al., 2003; Gibson and Jiang, 2001; Olivers and Humphreys, 2003; Watson and Humphreys, 1998]. For instance, Olivers and Humphreys [2003] showed that a saliently colored or oriented distractor loses its disruptive effect on search when it shares its color or orientation with the ignored, previewed items, even when the preview display has disappeared. They concluded that several features of the old items are inhibited (including their color and orientation) and some of this inhibition is carried over to new

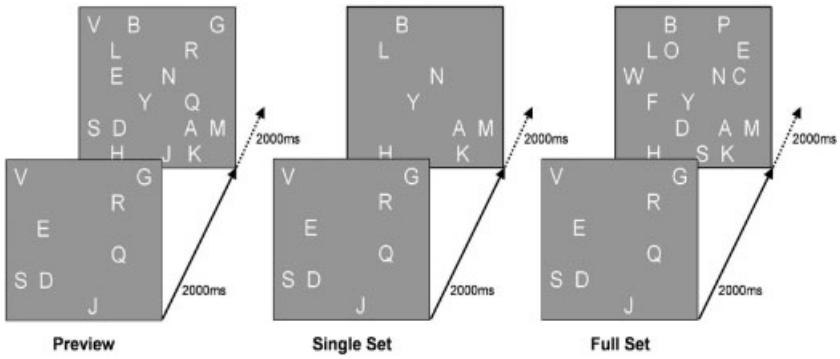

Figure 1.

Stimuli and experimental procedure. In all conditions, a preview display was followed by a search display. In the preview condition, previewed distractors remained on screen when search items were added. In the single-set and full-set conditions, the previewed items disappeared when the search set arrived. The final total set in the full-set condition was twice as large as that in the single-set condition and as large as that in the preview condition. The target is an N, and the final set size is 16 (8 in the single set). The target could also be a Z, and the set size could also be 8 (4 in the single set). Displays were followed by a 10-s blank period.

items based on their shared features. In their imaging study, Pollmann et al. [2003] used preview displays in which the old and the new items were not only defined by a difference in spatial location and temporal onset, but also by a color difference. Old items were always green and new items always blue. This was compared to single-set and full-set baseline conditions, in which a dummy preview of red circles was presented first, then disappeared when either a blue search set (in the single-set condition) or a blue and green search set (in the full-set condition) arrived. The conditions thus varied in the number of colors employed, and participants may have used these colors, rather than the spatiotemporal properties of the stimuli, to separate relevant (new) from irrelevant (old) items [Kastner et al., 1998; Wojciulik and Kanwisher, 1999; see also Theeuwes et al., 1998, for similar arguments]. The present study therefore used white letters drawn randomly from the alphabet and presented on a gray background. Under these circumstances, it is not possible for observers to use color as a cue to segment new from old. Moreover, the use of letters precludes any consistent feature differences between old and new items (such as shape and orientation). Instead, to segment new from old, participants would have to make use of just the spatiotemporal dynamics of the displays. Consequently, the present study provides a particularly rigorous test of the brain areas involved in spatiotemporal segmentation processes.

The procedure is illustrated in Figure 1. There were three main conditions, and in all cases, participants were presented with a 2-s preview display. This preview display contained a number of random letter distractors. In the single-set condition, the preview display then disappeared and was replaced with a 2-s search display, consisting of an equal number of letters, but including a target (either "N" or "Z"). In the full-set condition, the preview display again disappeared and was replaced with a search display consisting of double the number of letters, again including a target. Only in the preview condition did the preview display actually provide valid information about forthcoming old distractors. Here, distractors remained on screen and were then accompanied by an equal number of search items, including a target. In this way, at the end of the sequence the total number of items present in the preview condition matched that of the full-set condition, but the number of new items in the preview condition (i.e., the search items) matched that of the single-set condition. If observers are able to prioritize fully the new items in the preview condition, the search should thus match that of the single-set condition and be twice as efficient as that in the full-set condition.

By comparing the brain activation in the preview condition to that in the full-set and single-set baselines, we can extract the areas involved in actively prioritizing new over old information when old information remains in the display. In all three conditions, the first set was irrelevant, and observers were expecting the target to be in the second set. The attentional set for the new stimuli should thus be the same across conditions, but importantly, only in the preview condition could observers actively segment new from old to guide the subsequent search. We hypothesized that this would lead to distinct areas of activation relative to the single-set and full-set conditions, with the SPL specifically being a good candidate [see Pollmann et al., 2003].

We also assessed search-related activation by comparing the full-set to the single-set condition, because in the full-set condition search is assumed to be more effortful (as is confirmed by the behavioral data). We were thus able to assess areas differentiating or common to search- sand preview-related processes.

SUBJECTS AND METHODS

Subjects

Six male and six female participants volunteered (giving written informed consent), including the two authors (C.O. and G.W.H.). Subject recruitment procedure and protocol

was approved by the Oxford Research Ethics Committee. The age of subjects ranged from 22 to 45 years (average 28.0 years), two subjects were left-handed, and all had normal or corrected-to-normal vision.

Stimuli, Design, and Procedure

All stimuli were drawn in white on a gray square background and back-projected onto a screen viewed from the scanner through mirror goggles. As is illustrated in Figure 1, each trial started with a preview display containing either four or eight letters (29-point Helvetica font), randomly drawn from the alphabet with the exclusion of N and Z (which were the target items of the subsequent search display), and I and X (which were left out altogether because of their specific shape), and plotted randomly in a 6×6 virtual matrix. After the preview display was on for 2,000 ms, the search display appeared, consisting of another four or eight randomly drawn letters in locations unoccupied previously, and including either a Z or an N as the search target. Participants were instructed to keep their eyes still during the preview until the search set arrived and then decide as quickly and accurately as possible whether a Z or N was present in the new display, by pressing the corresponding button on a button box held in the right hand. To equate presentation times across conditions, the search display was always on for 2,000 ms, even if participants responded sooner than that. Participants could respond up to 1,000 ms after display offset. The trial ended with a 10-s rest period. A fixation cross was presented throughout the trial. There were three main conditions (single set, full set, and preview), and two set sizes (in total either 8 or 16 items, with 4 and 8 in the preview displays, respectively). In the single-set condition, the preview display contained either 4 or 8 distractor letters, which disappeared simultaneously with the onset of the search display. This search display also contained either 4 or 8 letters, respectively, all in previously unoccupied positions. Either 4 or 8 items were thus present when search started, all of which were new. In the full-set condition, the preview display contained 4 or 8 distractor letters, which again disappeared with the onset of the search display. The distractors were now replaced by either 8 or 16 new search items, presented at new locations. In the preview condition, the preview display contained 4 or 8 distractor letters, but these now remained on the screen when another 4 or 8 search items were added. Either 8 or 16 items were thus present when search started, of which half were old and half were new. Only in the latter condition did the preview display provide information about which items to ignore subsequently in the search display. For each combination of condition and set size, there were 16 trials (8 for each target type). The main conditions (single set, full set, and preview) were presented blocked, with set size (8, 16) and target type (N, Z) randomly mixed within blocks. Before each block, an on-screen instruction indicated the type of task. All data are reported collapsed across target type, which was not included as a factor in the analyses. In reporting the results, we use set sizes 8 and 16 to calculate search slopes, even though in the single-set condition there were only 4 and 8 search items present. This allows us to calculate the preview benefit [see Watson and Humphreys, 1997]: If old items are ignored effectively in search in the preview condition, then the search slope will measure half the slope of the full-set condition, and resemble the slope of the single-set condition. Block order was counterbalanced fully across subjects. All participants had practiced the complete experiment outside the scanner during a 2-week period before the scan session, and received a few warm-up trials just before the actual scanning commenced.

fMRI Measurement and Analysis

Brain activation was measured using a gradient echo planar imaging (EPI) sequence conducted in a 3T magnet (Oxford Magnet Technology) housing a Magnex SGRAD MK III head insert gradient coil. One volume was equivalent to 14 axial slices (7 mm thick, no gap) with a 256×256 mm (64×64 matrix) field of view, resulting in a voxel size of $7 \times 4 \times 4$ mm. Repetition time (TR) was 2 s, echo time (TE) was 30 ms, and the flip angle was 70 degrees. Each fMRI session consisted of three scans, one for each main condition. A scan started with four dummy volumes (8 s), followed by a 14-s fixation period. There were then 32 trials of 14 s each, synchronized with the TR. The scan ended with another 14-s fixation period. There was a short break between scans. Data were analyzed using BrainVoyager 4.9 (BrainInnovation, Maastricht, The Netherlands). Preprocessing consisted of global intensity normalization, 3-D motion correction, slice time correction using linear interpolation, Gaussian spatial and temporal smoothing (kernels full-width half-maximum [FWHM] = 5 mm, and FWHM = 2.8 s, respectively), Fourier transform-based high-pass filtering (0.02 Hz), registration to a high-resolution T1-weighted anatomic scan acquired for each subject, and finally, transformation into Talairach space [Talairach and Tournoux, 1988]. A random effects group (n = 12) analysis was carried out by multiple linear regression of the response time course at each voxel for each subject, following a linear model of the hemodynamic response [Boynton et al., 1996]. Three predictors were modeled corresponding to the three main conditions (single set, full set, and preview). The design used here did not allow for separate extraction of the two consecutive events of the preview and search display (2 s each) and the model thus treated the combination of preview and search displays as one 4-s event. BrainVoyager's group t statistics (degrees of freedom [df] = 11) were then converted to z statistics and thresholded using clusters determined by $z > 1.96$ and a (corrected) cluster significance threshold of $P = 0.05$ [Forman et al., 1995; Friston et al., 1994; Worsley et al., 1992]. The Gaussian-distributed Random Field (GRF)-based cluster analysis was carried out using FMRI Expert Analysis Tool (FEAT) v.5.1, part of the software library at FMRIB (online at http://www.fmrib.ox.ac.uk/fsl). The resulting clusters were then used as masks for the original t image, which was thresholded once more at $t(11) = 2.6$. All reported clusters have a volume

>112 mm^3 (the original voxel size) and peak activity of at least $P < 0.01$.

RESULTS

Behavioral Data

The error percentages are shown in Table I. On average, 10.9% errors were made, which seems reasonable given the nonoptimal viewing conditions. There were no significant main effects or interactions of condition and set size (all values for $F < 1$, all values for $P > 0.4$).

Reaction times (RTs) of the correct trials were averaged for each participant and entered in a within-subject analysis of variance (ANOVA) with condition (single set, full set, and preview) and set size (8, 16) as factors. There was a main effect of condition ($F[2,22] = 7.50$, $P < 0.01$). Figure 2 shows that overall RTs were longest in the full-set condition. Separate analyses confirmed that RTs in the full-set condition were longer than those in the preview condition ($F[1,11] = 12.74$, $P < 0.01$), but that there was no difference between the preview and single-set conditions ($F[1,11] = 0.012$, $P = 0.915$). There was also a main effect of set size ($F[1,11] = 97.2$, $P < 0.001$), as RTs increased with a higher number of search items in all conditions. Finally, there was a condition $\times$ set size interaction ($F[2,22] = 9.85$, $P = 0.001$). As Figure 2 indicates, set size had a stronger effect on search in the full-set condition than in the preview and single-set conditions, resulting in steeper slopes. Separate analyses confirmed a Condition $\times$ Set size interaction when contrasting the preview to the full-set condition ($F[1,11] = 12.17$, $P < 0.01$), but not when contrasting the preview to the single-set condition ($F < 1$, $P > 0.5$).

The behavioral data thus demonstrated a strong benefit in the preview condition compared to the full-set baseline. Performance in the preview condition was as good as in the single-set condition. Consistent with earlier findings, observers do not need a feature difference (such as color, orientation, or shape) to be able to fully segment new from old items in search [Olivers et al., 1999, 2002; Theeuwes et al., 1998]. Instead, observers can make use of the spatiotemporal differences in the search displays to bias selection against old items and in favor of new items.

Functional Imaging Data

To assess search-related activity, we contrasted the full-set condition (in which search was more effortful) to the single-set condition (in which search was less effortful). To assess preview-related activity, we contrasted the preview condition (with a valid preview) to the single-set condition as well as to the full-set condition (both without valid previews). Figure 3 and Table II show the areas involved.

TABLE I. Error percentages in the search tasks

	Error (%)	
Condition	Set size 8	Set size 16
Single set	10.4	8.3
Full set	11.5	10.4
Preview	9.4	15.1

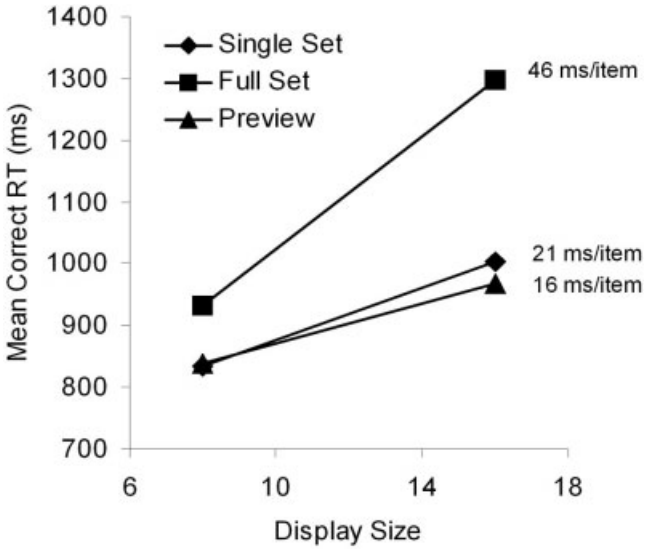

Figure 2.
Behavioral data: Average reaction time search functions for the single-set, full-set and preview conditions.

Search-related activity (full set–single set)

The lateral premotor area located on the precentral gyrus (Brodmann area [BA]6) of the left hemisphere was more active in the full-set condition than in the single-set condition. Other regions of activation involved the dorsolateral prefrontal cortex, notably the inferior and middle frontal gyri (BA9/46) in both hemispheres, extending to the insular regions.

Preview-related activity (preview–single set)

Comparing the preview condition to the single-set condition revealed activation in the SPL (BA7), extending into the precuneus of the right hemisphere. Similar activation was found in the left hemisphere, but to a smaller and weaker extent. More inferior parts of the precuneus (extending subgyrally) in the right hemisphere were also active.

Preview-related activity (preview–full set)

The final contrast compared the preview condition to the full-set condition. This again showed activation in the SPL (extending into the precuneus, BA7) of the right hemisphere, largely overlapping with the area found in the preview–single set contrast. The same area was also active in the left hemisphere, although again weaker and less spread. The

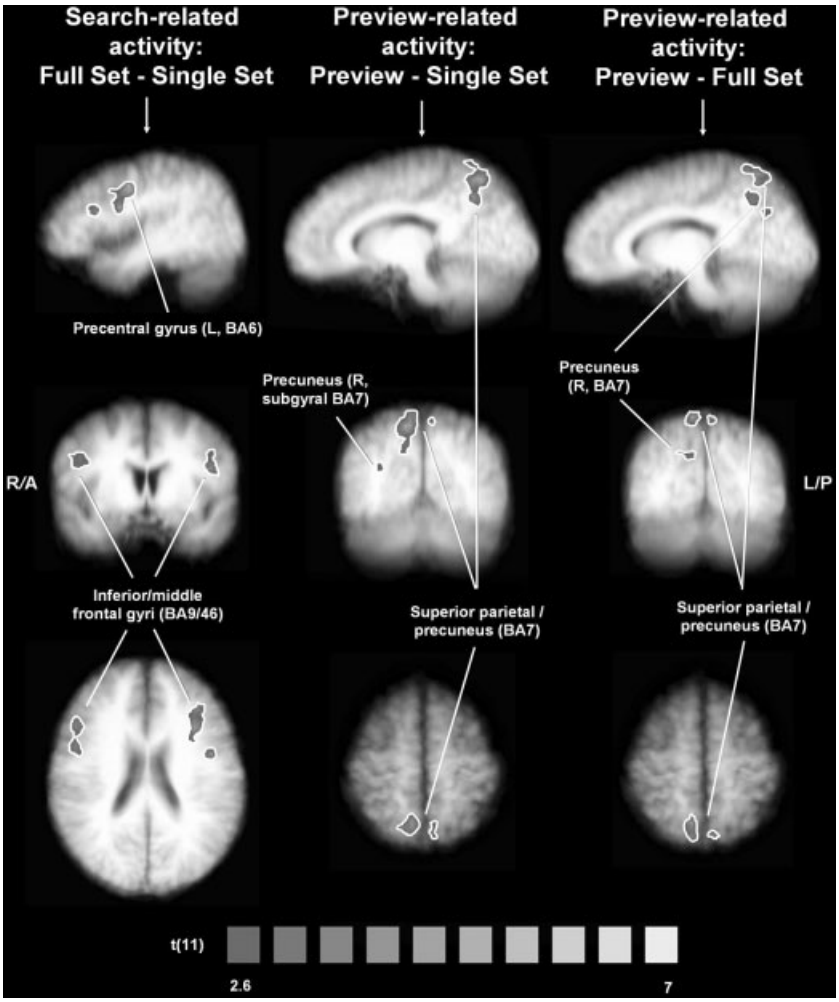

Figure 3.
Areas of activation for various contrasts averaged across 12 participants presented on sagittal, coronal, and axial slices of their normalized and averaged structural scans. Graphs were not chosen for maximum level of activity, but for maximum overview of the activated areas. There were no significantly deactivated areas.

more inferior part of the precuneus in the right hemisphere was also active.

DISCUSSION

Preview

The two contrasts involving the preview condition (preview–single set and preview–full set) show important common areas of activation in the superior and more inferior medial parietal lobules. The superior parietal areas lie remarkably close to those reported by Pollmann et al. [2003], who found significant activation in the right SPL in one experiment and the left SPL in another ($x = 7$, $y = -65$, $z = 50$, and $x = -7$, $y = -62$, 52, respectively). In contrast to Pollmann et al. [2003], whose old and new sets differed in color, we used stimuli that could only be distinguished based on their spatiotemporal properties. We can thus conclude safely that the SPL is involved in active segmentation of old and new items based on these spatiotemporal properties.

The more inferior medial activation of the precuneus corresponds closely to areas reported previously to be active during spatial attention and spatial working memory tasks [Corbetta et al., 1993; Giesbrecht et al., 2003; Owen et al., 1996] as well as during temporal orienting and combined spatial and temporal orienting [Coull and Nobre, 1998]. We propose that, together with the SPL, it serves to maintain a spatiotemporal bias against to-be-ignored locations, in favor of to-be-searched locations. In all, the parietal activation is reminiscent of activation found in numerous neuroimaging studies as part of an emerging general top–down frontoparietal attention network [for reviews see Corbetta, 1998; Kanwisher and Wojciulik, 2000; Kastner et al., 1999]. It provides support for the idea that observers actively bias attention toward the new items in the preview task.

Posterior Parietal Function

The present experiment does not address the issue of whether the SPL underlies inhibition of old distractors or the maintenance of these items in a spatial map that helps bias subsequent search against these locations. The activation does not seem to reflect activation from new search items because that activation should have been common to the preview and baseline search conditions. It could also be

TABLE II. Areas of activity for search-related (full set–single set) and preview-related (preview–single set and preview–full set) comparisons

Structure (BA)	Location *x, y, z* (mm)	Volume (mm^3)	Max *t* (*df* = 11)
Search-related activity: full vs. single set			
Mid frontal gyrus (BA9/46) extending to inf frontal gyrus and insula (BA13/45/46)	R 44,12,23 extending to 45,3,23; 46,24,26; 46,19,16	2,370	5.50
	R 31,30,11	531	5.27
	L −43,18,19	1,254	5.46
	L −34,25,19	175	3.76
Precentral gyrus (BA6) extending to inf frontal gyrus (BA44)	L −40,−3,30	1,519	7.80
Preview-related activity: preview vs. single set			
Sup parietal lobule/precuneus (BA7)	R 10,−59,50 extending to 7,−62,58; 8,−53,62; 12,−57,36	2,757	4.99
	L −6,−63,55	131	3.34
Precuneus (BA7) extending subgyrally	R 26,−57,29	261	3.30
Preview-related activity: preview vs. full set			
Sup parietal lobule/precuneus (BA7)	R 13,−58,57 extending to 17,−50,62; 7,−68,53; 9–61,50	1,798	6.70
	L −4,−67,56	134	4.03
Precuneus (BA7) extending to cuneus	R 13,−59,37 extending to 12,−55,41; 10,−66,31	678	3.51

BA, Brodmann area; mid, middle; inf, inferior; sup, superior; R, right; L, left.

argued that the preview-related activity was caused by a spatial expectancy of where the target items would appear, with more attention being applied to the preview in this condition. We agree that more attention was likely paid to the first display in the preview than in the other search conditions, but we suggest that this was to bias search away from the old items rather than to form a spatial expectancy for new stimuli. This is because the same expectancy could have been generated in the single-set and full-set baselines too, because in these conditions, the new items also appeared in spatial locations that were always different from those used in the first set of (previewed) items.

The SPL/precuneus, together with more occipital regions, was also active in an earlier positron emission tomography (PET) investigation of the preview task, when measured against a simple detection baseline with stimuli defined by color and shape differences [Humphreys et al., 2004]. In that study, the length of the preview period was varied between 300, 600, and 900 ms, and activation in the critical parietal and occipital areas increased with longer preview periods. Interestingly, the time taken for search was reduced across these intervals so increased activation was linked to enhanced filtering of distractors and not to search difficulty. Whereas in the studies of Pollmann et al. [2003] and Humphreys et al. [2004], participants may have employed color differences to segment relevant from irrelevant stimuli [compare to Kastner et al., 1999], participants in the present study could only make use of the spatiotemporal differences. Taken together, the findings point toward an important role for the SPL in top–down spatiotemporal selection against old information in favor of new information.

We have found recently additional evidence that the parietal lobe plays a crucial role in distinguishing new from old items [Olivers and Humphreys, in press]. We presented patients suffering from posterior parietal damage with a preview task and compared them to age-matched controls. Control participants could effectively ignore the old items and prioritize the new set (resulting in a preview benefit). The patients had severe difficulties in detecting the new target, to the extent that there was no benefit and sometimes even a cost relative to a full-set baseline in which all items were presented simultaneously. This result held even when search was made easier or when segregation between old and new was promoted by an outline shape drawn around the old items. We concluded that this group of patients had difficulties either with segmenting new from old, or with disengaging from old information after possibly successful segmentation [compare with Petersen et al., 1989; Posner et al., 1984]. Interestingly, Friedmann-Hill et al. [2003] report on a patient (R.M.) with bilateral posterior parietal damage (mainly BA7 and 39), who was severely impaired at ignoring distractors when having to identify a target, even though this target was always presented at the same location. This was especially the case with salient distractors, and also held for stimuli that R.M. could identify without difficulty if distractors were not present. The authors concluded that R.M. has an "inability to suppress the influence of irrelevant objects." Together with our study, these data suggest that the posterior parietal area is a source for filtering distractors, whether presented simultaneously with or in advance of relevant target information.

Although the present study indicates that specifically the SPL (together with the more inferior parietal activation) plays a particularly important role in the preview task, the patient studies mentioned are more likely to reflect a variety of parietal function loss. Exactly how the parietal cortex

should be subdivided functionally remains an important question. Traditionally, the SPL has been assigned a role in spatial processing, but also in implementing expectations (which emphasizes its temporal character) [Corbetta et al., 1993; Coull and Nobre, 1998; Hopfinger et al., 2000; Kastner and Ungerleider, 2000; Owen et al., 1996; Posner et al., 1984]. Others have found the more inferior and lateral intraparietal sulcus (IPS) as the main source of spatial or temporal selection-related activation (sometimes alongside SPL activation) [Coull and Nobre, 1998; Gitelman et al., 1999; Hopfinger et al., 2000; Kanwisher and Wojciulik, 2000; Marois et al., 2000; Owen et al., 1996; Shulman et al., 1999; Vandenberghe et al., 2000; for monkey IPS see also Gottlieb et al., 1998].

Temporoparietal Junction

Unlike that in the study by Pollmann et al. [2003], the present preview–full set contrast revealed no consistent activity in the temporoparietal junction area (TPJ; superior/middle temporal gyri), although we found some subthreshold activation. Pollmann et al. [2003] argued that the TPJ reflected target-related activity from the search stage, following earlier evidence that the TPJ plays a crucial role in detecting salient and potentially relevant events [Corbetta et al., 2000; Corbetta and Shulman, 2001; Downar et al., 2001; Friedrich et al., 1998; Shapiro et al., 2002; Vallar, 1993]. It is therefore likely to be more responsive to the less effortful search conditions in which targets are relatively more salient and thus more likely to capture attention. In line with this, Pollmann et al. [2003] found similar activity when the single-set search was contrasted to the full-set search. We used random letter displays in all conditions, rather than the single feature/conjunction displays used by Pollmann et al. [2003]. The difference in target saliency between the easy and more effortful searches may therefore have been less distinctive here than in the above study.

Prefrontal Areas

An important extension to earlier findings is that the preview-related activation could be dissociated from additional activation related to the search process. The search-related contrast (full set–single set) showed activity of the dorsolateral prefrontal cortex and the premotor cortex. Numerous previous studies reported identical or very similar areas in association with either increased effort in search [Donner et al., 2002; Nobre et al., 2003] or with related attention tasks, especially those involving endogenous attentional and oculomotor shifts [Corbetta, 1998; for reviews see Coull and Nobre, 1998; Kastner and Ungerleider, 2000]. The increased activity may reflect the additional spatial orienting associated with the presence of more items. Alternatively, it may reflect the recruitment of attentional resources necessary to reject and ignore additional distracting information [Banich et al., 2000; Bunge et al., 2001; Lavie 2000]. One such mechanism would be "inhibition of return" (i.e., the tendency of attention to reorient more slowly to previously visited locations), applied to distractors in the search displays [Klein, 1988; Müller and Von Muhlenen, 2000; Shore and Klein, 2000; Takeda and Yagi, 2000]. It is interesting in this respect that Lepsien and Pollmann [2002] found virtually the same dorsolateral prefrontal cortex (DLPFC) areas (among other areas) to be active in conditions inducing inhibition of return.

Of further relevance is a behavioral study by Olivers et al. [2002] comparing a condition in which participants first fully searched a preview set and then searched a newly added set to a condition in which participants ignored the preview set before they searched the newly added set. Olivers et al. [2002] found that old searched distractors interfered more with subsequent search than did old ignored distractors. This suggests that "ignoring in advance" (i.e., visual marking) and "ignoring during search" (memory in search or inhibition of return) are not the same process. The present data seem to be consistent with this idea. Whereas the DLPFC may be involved in (serially) suppressing irrelevant visual information presented simultaneously with the target information, the SPL and inferior parietal regions may be more involved in parallel filtering of distractors across time, in advance of the target information.

ACKNOWLEDGMENTS

This work was supported by the Medical Research Council, UK. A British Council/NWO travel grant was awarded to C. Olivers.

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